SESSION I

N76-19447

ROLAMITE DESIGN USING FIGURES OF MERIT

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ABSTRACT

Band material properties are discussed in terms of two figures of merit that allow materials to be ranked by their performance. One ranks materials of equal thickness by ability to wrap around small diameter rollers. The second ranks materials by the maximum force generated for a specified roller size. Results are tabulated for a wide range of materials. The figures of merit are used to compute minimum and maximum sizes for certain classes of rolamites.

INTRODUCTION

A rolamite has three basic parts: rollers, band, and guide surfaces. Of these, the band is the most critical. It must flex back and forth at least once during each operation of the rolamite; it may have cutouts for force generation, and it may be under high tension as in a locked geometry. On the other hand, the rollers and guide surfaces are massive and only lightly loaded. This suggests that rolamite design is closely tied to band properties, and the performance of rolamites depends heavily on the particular band material chosen.

Figures of merit that rank materials by their performance as band materials will be presented. The measures are analogous to the strength-to-weight ratio in aeronautical engineering or the stiffness ratio in structural engineering. The engineer can use the rolamite figures of merit and other factors, such as relative cost and environmental conditions, to select the best band material for his particular application.

ROLAMITE FIGURES OF MERIT

Two figures of merit are critical to rolamite design. The first, called the flexivity, F_1, is the maximum band thickness that can be bent around a particular roller size. The importance of flexivity is not apparent from this definition alone. Thicker bands are more easily handled, easier to produce, and generally cost less. Also, if two bands of the same thickness are compared, the one with the better flexivity can be used with smaller rollers, making the overall rolamite smaller. The second figure of merit, called the force factor, F_2, ranks materials according to their force-generating capabilities. For a particular roller size it is a measure of the force that can be produced with band cutouts.

The flexivity and force factors are defined in terms of strength and elastic modulus. As a rolamite operates, the band is flexed back and forth (Figure 1). The strength (or stress) to be used in calculating the figures of merit is related to the material's ability to withstand this type of motion. Data that give the flexures-to-failure at various stress levels are available for most materials (Figure 2). Typically, a definite stress exists, called the endurance stress, below which the material can be flexed an infinite number of times without failing. This value is used for the strength in the flexivity and force factors for rolamites that must operate millions of cycles.

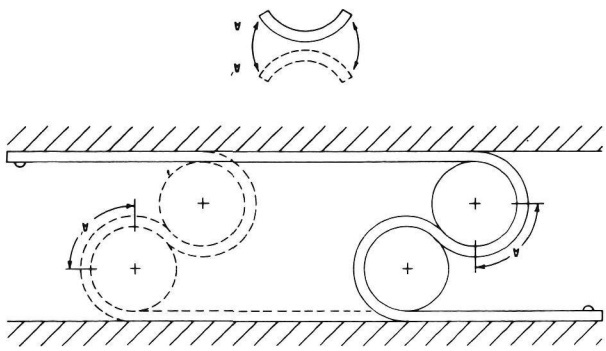

Figure 1. Band Flexure During Rolamite Operation

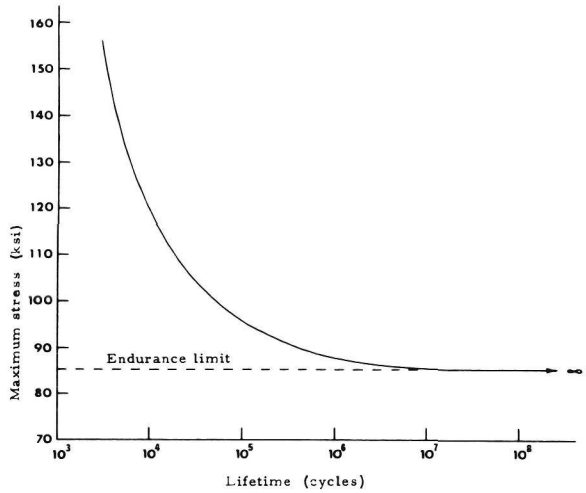

Figure 2. Flexural Fatigue Strength of Titanium Alloy (Ti-6Al-4V)

For a very small number of operations, a different material limitation becomes important. The band may withstand flexing at very high stress levels, but it may permanently deform. As a result, the band would offer a great deal of resistance to roller cluster motion. The best measure of the onset of permanent deformation is the 0.02 percent offset yield stress (that is, the stress at which a material permanently deforms by 0.02 percent). However, it is rarely tabulated, so the more common 0.2 percent yield stress must be used. Experience has shown that rolamites with bands operating at the 0.2 percent yield stress are noticeably affected by the permanent band deformation, and the 0.2 percent yield stress must be considered an upper limit and not a stress level for general operation.

With these definitions of stress, the flexivity and force factor can be defined in terms of material properties and quantities related to the rolamite geometry:

$$F_1 = \sigma/E = t_m/d, \tag{1}$$

$$F_2 = \sigma^3/E^2 = 6F_m/d\Delta w, \tag{2}$$

where:

F_1 = flexivity

F_2 = force factor

σ = stress (endurance or 0.02% or 0.2% yield)

E = elastic modulus

t_m = maximum band thickness

d = roller diameter

F_m = maximum force that can be generated by band cutouts

Δw = difference in cutout width at ends of band's contact with rollers

Again, either the endurance or yield stress can be used in the formulas. The choice depends on whether endurance or limited operations are of interest. To denote the corresponding values of F_1 and F_2, the following notation is used:

F_{1e} = endurance flexivity,

F_{2e} = endurance force factor,

and

F_{1s} = single operation flexivity,

F_{2s} = single operation force factor.

The choice of which figure of merit to use in designing rolamites depends on whether size or force generation is the more important. In any event, the larger the figure of merit, the better the material for that application.

FIGURES OF MERIT VALUES

Values are given in Tables I and II for two classes of materials: the first class, and for general purposes the most important, is corrosion-resistant metals. The second class is metals that rust or readily corrode in other ways, and nonmetallic materials. Also presented are relative cost data for moderate quantities of the materials, maximum service temperature, electrical conductivity, and other pertinent characteristics.

Several materials--titanium alloys, a stainless steel alloy, cobalt-based alloys, beryllium copper, spring steels, two maraging steels, rubbers, and plastics--have the highest flexivities. A titanium alloy, a spring steel, cobalt-based alloys, and two maraging steels have the highest force factors. The choice of the best material for a particular application is a balance of the value of the appropriate figure of merit with other factors such as cost, operating temperatures, corrosive nature of the environment, fabricating ease, and cycles of operation.

TABLE I

Flexivities and Force Factors for Corrosion-Resistant Alloys[1]

Alloy	F_{1s} $\times 10^{+3}$	F_{1e} $\times 10^{+3}$	F_{2s} (psi)	F_{2e} (psi)	Yield Strength $\times 10^{-3}$ (psi)	Endurance Strength $\times 10^{-3}$ (psi)	Elastic Modulus $\times 10^{-6}$ (psi)	Maximum Service Temperature	Cost Index[2]	Electrical Conductivity (% IACS)	Notes
Titanium											
Beta	11.0	4.8	20.3	1.75	170	75	15.5	450°F	6	1.1	Not available in thinner gages
6-6-2	10.9	4.7	20.8	1.64	175	75	16	750	6	1.2	
6-4	10.3	5.4	29.0	2.66	170	90	16.5	750	6	0.9	
Stainless Steel											
Sandvik 11R51	11.7 (10.5)[3]	3.3	46.2 (34.4)	1.05	335 (300)	95	28.5	800	1.5	2.0	Relatively inexpensive; good overall properties
17-7 Ph	9.0	2.8	20.8	0.64	260	80	29	650	0.8	2.1	
AM-350 CRT	8.8	2.4	19.6	0.41	255	70	29	550	1	2.5	
Nickel											
Inconel 718	8.8	3.0	20.0	0.83	260	90	29.5	1300	3	1.4	High temperature alloys
Inconel X750	8.1	1.9	16.1	0.22	250	60	31	1350	2	1.4	
Berylco Nickel 440	7.9	3.3	14.4	1.02	230	95	29	700	2	7.0	Good life with cutouts
Rene 41	7.6	2.0	13.8	0.25	240	63	31.5	1400	4	na	High temperature
Cobalt											
Elgiloy	11.2 (9.5)	3.0	41.2 (25.0)	0.83	330 (280)	90	29.5	900	5	0.6	Very inert; uniform qualities
Havar	11.2 (9.5)	3.0	41.2 (25.0)	0.83	330 (280)	90	29.5	900	5	2.7	
Other											
Paliney 8	10.6	-	19.1	-	170	na	16	na	180	6.7	Platinum alloy; very inert at high temperatures
Beryllium Copper	10.3	3.2	19.9	0.63	190	60	18.5	350°F	1	22	Relatively inexpensive
Ni-Span-C 902	6.8	2.0	7.8	0.20	170	50	25	200	1.5	1.7	Force factor does not change with temperature
Elinvar Extra	6.5	-	7.7	-	180	na	27.5	200	4	na	

(1) Data taken from manufacturer's material property sheets, and "Flat Spring Materials," Product Engineering, March 1, 1965.

(2) Ratio of cost to cost of spring steel.

(3) Values in parentheses at 0.02% offset.

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TABLE II

Flexivities and Force Factors for General Materials[1]

Material	F_{1s} $\times 10^{+3}$	F_{1e} $\times 10^{+3}$	F_{2s} (psi)	F_{2e} (psi)	Yield Strength $\times 10^{-3}$ (psi)	Endurance Strength $\times 10^{-3}$ (psi)	Elastic Modulus $\times 10^{-6}$ (psi)	Maximum Service Temperature (°F)	Cost Index[2]	Electrical Conductivity (% IACS)	Notes
Spring Steels											
SAE 1095	9.7	3.9	28.1	1.79	300	120	31	400	1	na	Rust at 60% relative humidity
SAE 1074	9.7	3.9	28.1	1.79	300	120	31	400	1	na	
Maraging Steels											
350	13.1	4.6	61.2	2.7	355	125	27.0	900	0.8	na	Not available in very thin gages
300	11.3 (9.4)[3]	4.5	39.4 (23.1)	2.5	310 (260)	125	27.5	900	0.6	na	
250	10.7 (8.3)	4.3	33.3 (15.2)	2.1	290 (225)	115	27.0	900	0.5	na	
Medium Alloy Steel											
Vascojet 1000	7.1	4.3	10.9	2.4	215	130	30.4	1000	0.5	na	Not available in very thin gages
Plastics											
Vinylidene chloride-vinyl chloride	125	-	156	-	10[4]	na	0.08	160	0.1	0	Force factors much lower than those given; materials take a permanent set
Polypropylene	78	-	110	-	18	na	0.23	220	0.1	0	
Polyimide	31	-	13	-	14	na	0.45	150	0.4	0	
Polyester	28	-	19	-	23	na	0.80	300	0.6	0	
Rubbers											
Neoprene	5300	-	2.8×10^5	-	3.7	na	0.0007	400	0.4	0	Potentially very high force factors
Natural	5600	-	4.2×10^5	-	3.9	na	0.0006	200	0.4	0	

(1) Data taken from manufacturer's material property sheets.

(2) Ratio of cost to cost of spring steel.

(3) Values in parentheses at 0.02% offset.

(4) 5 percent offset.

PERFORMANCE LIMITS OF ROLAMITES

The figures of merit can be used to determine the size and operating capabilities of rolamite devices. As an example, a minimum size of a rolamite can be estimated. If the band choice is restricted to the corrosion-resistant materials of Table I and the band is assumed to be 0.0001 in. thick (a practical minimum), Equation 1 is used to compute the corresponding roller sizes for endurance and limited operation. Then, from Figure 1, the minimum rolamite size can be estimated. Results are summarized in Table III.

TABLE III

Size Limits for Rolamites

	Minimum Size		Maximum Size	
Parameter	Single Operation	Endurance	Single Operation	Endurance
Figure of merit	$F_{1s} = 10.5$	$F_{1e} = 3.3$	$F_{2s} = 34.4$	$F_{2e} = 2.66$
Band thickness (in.)	0.0001	0.0001	0.037	0.0015
Roller size (in.)	0.010	0.030	3.6	0.28
Overall height (in.)	0.020	0.060	6	0.45
Length (in.)	0.040	0.120	10	0.7

Table III also gives an upper size limit for rolamites that must withstand moderate vibration or shock and operate at all orientations (in essence, the general industrial environment). The limit is found by requiring the available force (from the force factor in Table I) to be ten times the roller weight. With this condition, the rollers will be relatively insensitive to orientation and modest vibration. The calculations assume that the rollers are solid aluminum and that no auxiliary elements such as springs are used. For hollow rollers, or rollers made of very light materials, the limit increases.

As a final example, the force factor can be used to determine the speed of action (acceleration) achievable for a particular roller diameter. The limit is important for rolamites if a high holding force or a "snap action" is needed. Again, the computations are based on conventional rolamites with solid aluminum rollers and metals from Table I. Results are presented in Figure 3. High accelerations, corresponding to rapid action, are possible with very small rolamites, while larger rolamites have slower action. The curves also show that single operation performance is appreciably better than endurance performance, as was the case with the other limits.

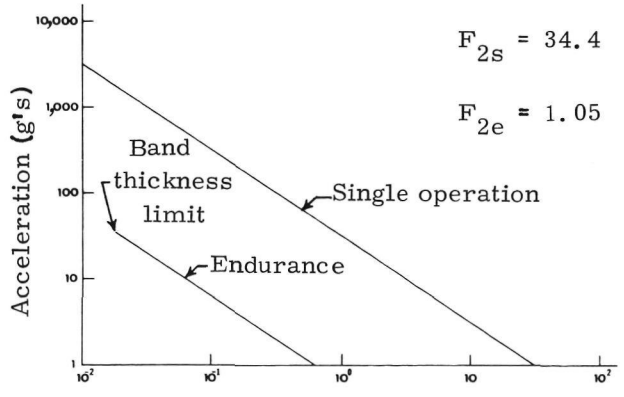

Figure 3. Maximum Roller Cluster Acceleration